14-15 DECEMBER 2022 | GRENOBLE, FRANCE

ESLS 2022

European Synchrotron
Light Source Workshop

ESRF - Operation & upgrade status, economy plan

Nicola Carmignani, on behalf of the
Accelerator and Source Division of ESRF

ESRF | The European Synchrotron

OUTLINE

- **Operation statistics**
- **Beam current evolution for timing modes**
- **Reduction of injection perturbations**
- **RF future plans**
- **Booster**

BEAM AVAILABILITY

Statistics of beam availability improved in the last year.

2022 is comparable with last year before long shutdown.

	2018	2020	2021	2022
Availability (%)	*98.5*	96.1	**96.4**	**99.1**
Mean Time Between Failures (h)	*104.3*	46.0	**66.4**	**88.5**
Mean duration of a failure (h)	*1.60*	1.80	**2.42**	**0.83**

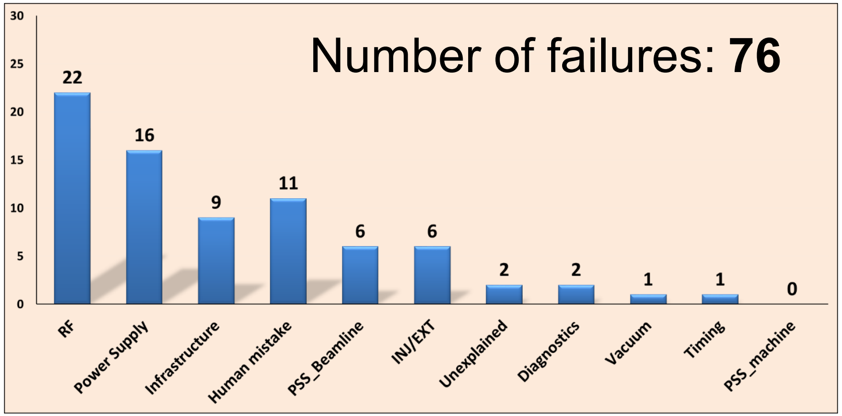
DETAILED STATISTICS 2022 (J-L. REVOL, L. HARDY)

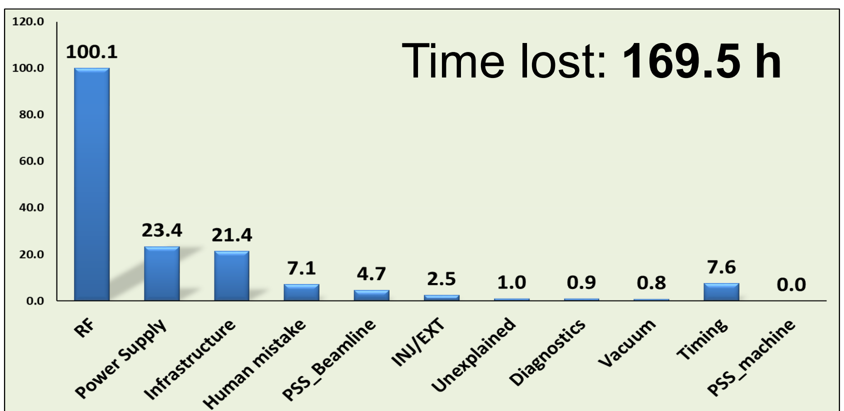
RUN NUMBER	2022-01	2022-02	2022-03	2022-04	2022-05	TOTAL 2022
Start	14/01/2022	25/03/2022	20/05/2022	19/08/2022	21/10/2022	
End	15/03/2022	11/05/2022	27/07/2022	12/10/2022	13/12/2022	
Total number of shifts	180.00	141.00	204.00	162.00	160.00	847.00
Scheduled Beam Time (h)	1152.00	906.00	1344.00	1056.00	1032.00	5490.00
Delivered Beam Time (h)	1147.70	900.90	1326.00	1046.60	1017.30	5438.50
Availability	99.63%	99.44%	98.66%	99.11%	98.58%	99.06%
Dead time for failures	0.37%	0.56%	1.34%	0.89%	1.42%	0.94%
Number of failures	7	8	17	11	19	62
Mean time between failures (h)	164.6	113.3	79.1	96.0	54.3	88.5
Mean duration of a failure (h)	0.61	0.64	1.06	0.85	0.77	0.83
total duration of failures (h)	4.3	5.1	18	9.4	14.7	51.50
Number of topup refills	1144	899	1313	1042	1016	5414
Number of skipped topup refills	18	32	22	11	4	87
	1.6%	3.6%	1.7%	1.1%	0.4%	1.6%

In 2022, we had less failures than in 2021 and they were shorter.
The number of skipped refills significantly decreased in the second part of 2022.

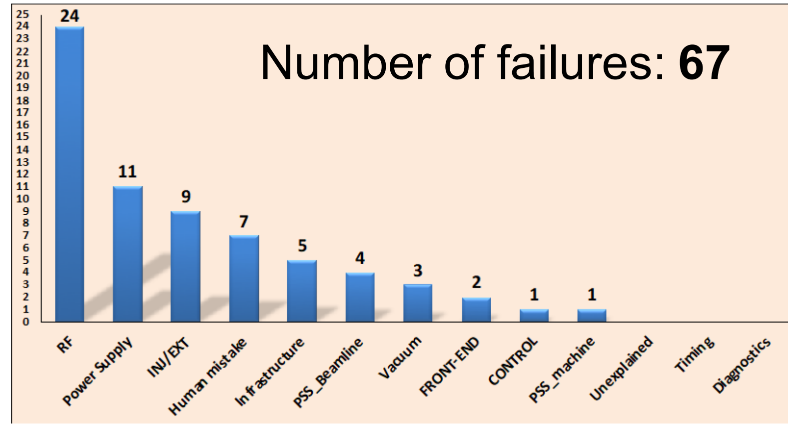
FAILURES IN 2022 COMPARED WITH 2021 (J-L. REVOL)

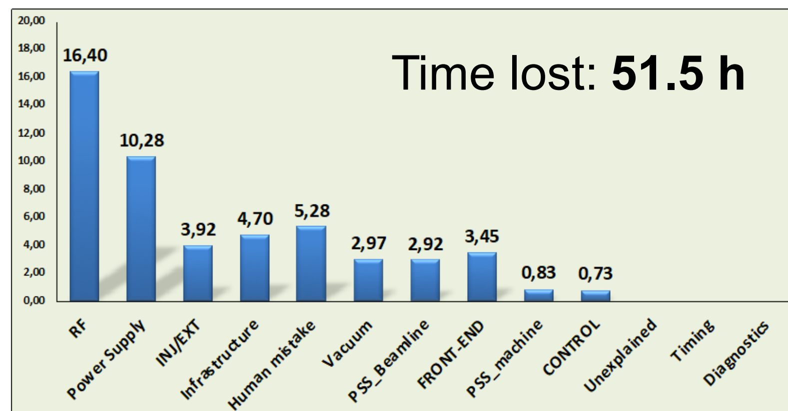
2021





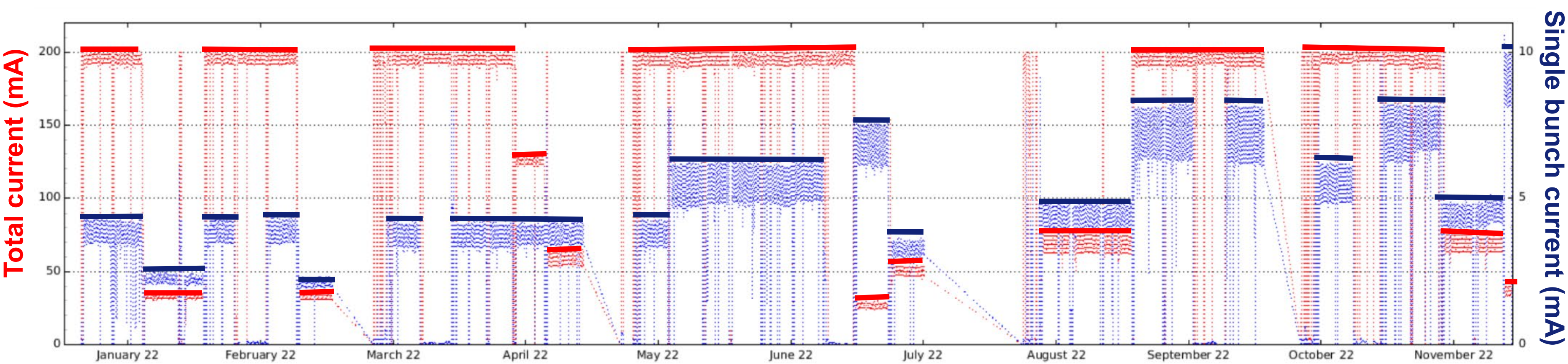
2022





CURRENT EVOLUTION IN 2022

In the winter and march shutdowns, the ceramic chambers of the kickers have been exchanged with identical ones with more coating to reduce the heat load.



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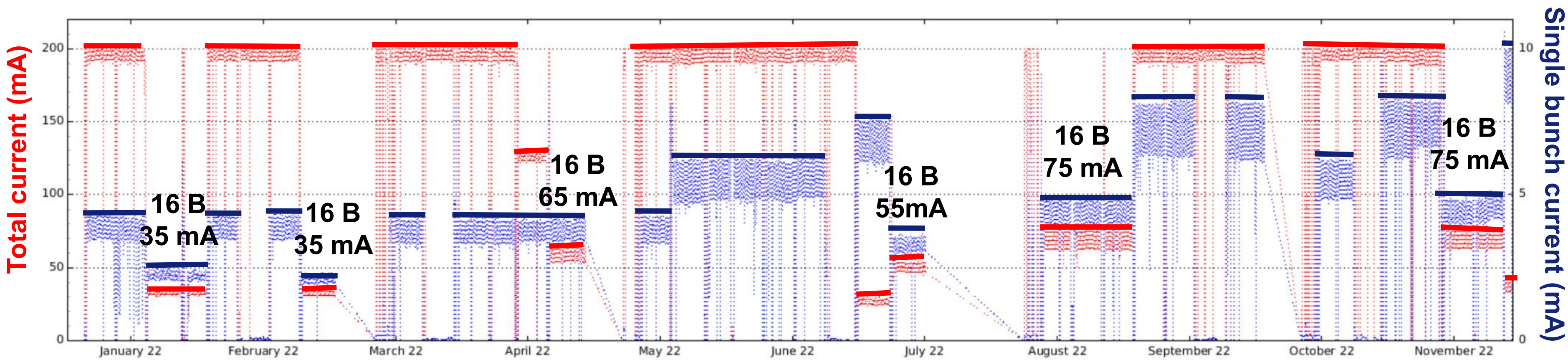
In 16 bunch mode, the current has been increased in May during MDT to 75 mA, but heating of the RF fingers of ID15 (and ID16) cryo-undulators was observed and limited the current to 55 mA,
After summer interventions the current has been increased to 75 mA.



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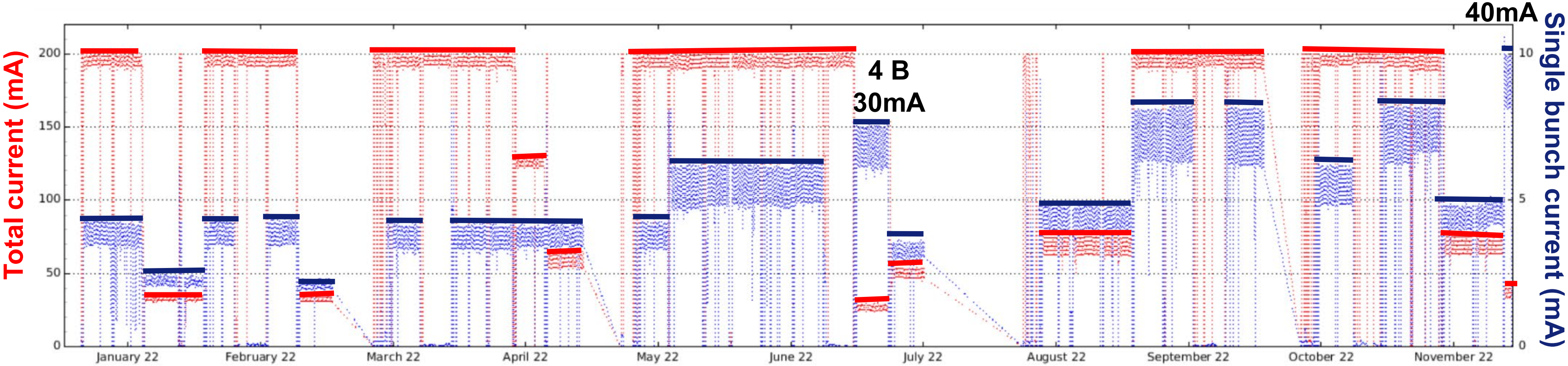

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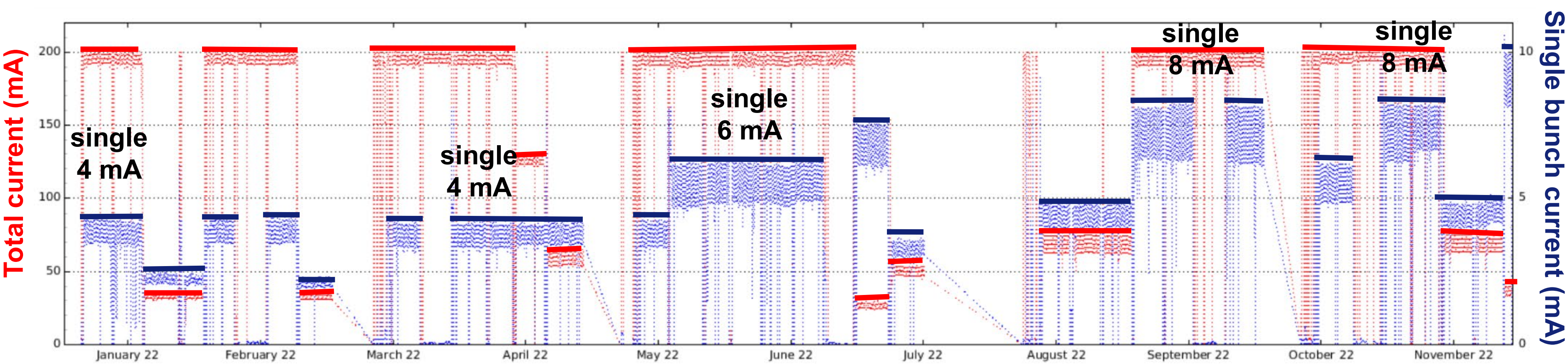
The current in the single bunch of the 7/8+1 mode was progressively increased from 4 to 8 mA.



INJECTION PERTURBATIONS WITH SLOW KICKERS

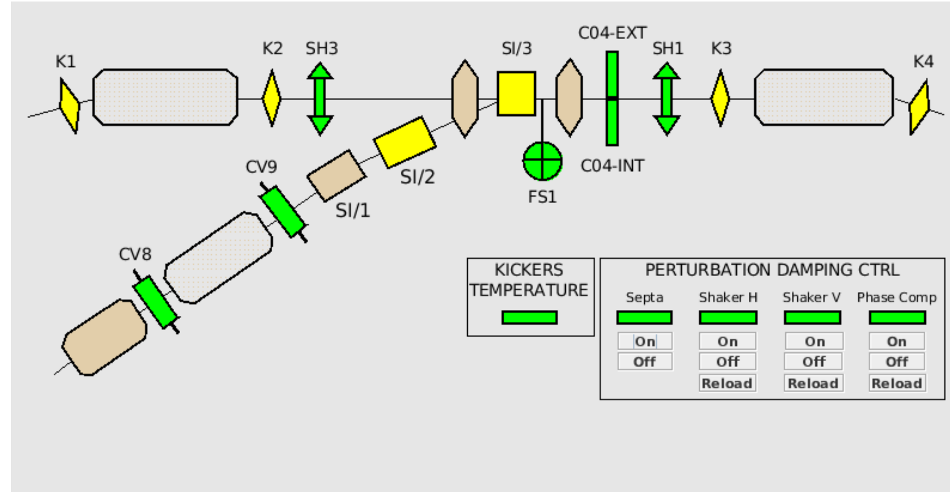
Injection at ESRF is performed at 4 Hz with a 4 kickers bump (K1, K2, K3 and K4), 2 electromagnetic septa (SI2 and SI3) and 1 permanent magnet septum (SI1).

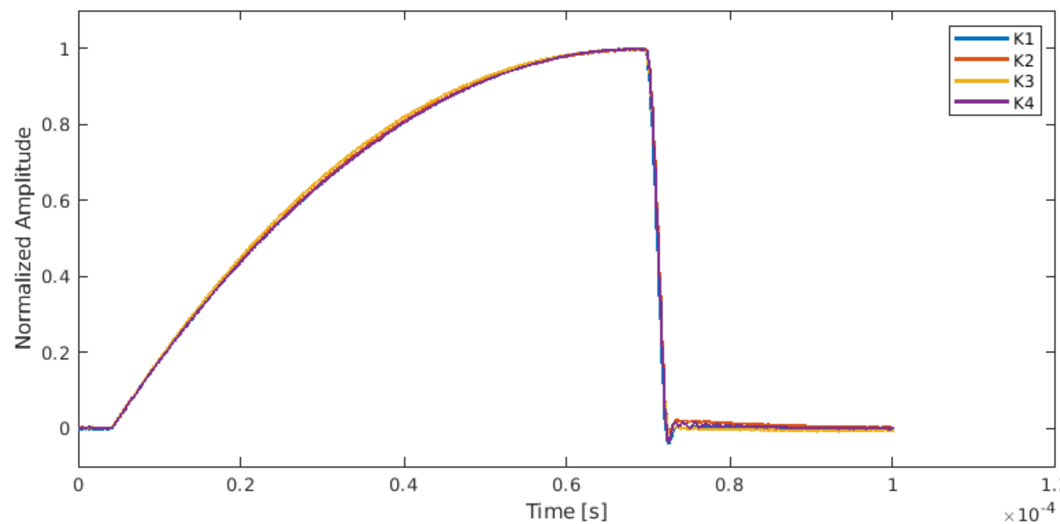
Injection perturbations are caused by the septa and by the not closure of the bump.

In 2021, the kicker power supplies have been changed with slower ones, resulting in a more closed injection bump.

Different ways to compensate the perturbations are used at ESRF:

- Septa compensation using fast correctors in a few cells.
- Kicker compensation using a magnetic shaker.
- Longitudinal compensation using RF phase shift.

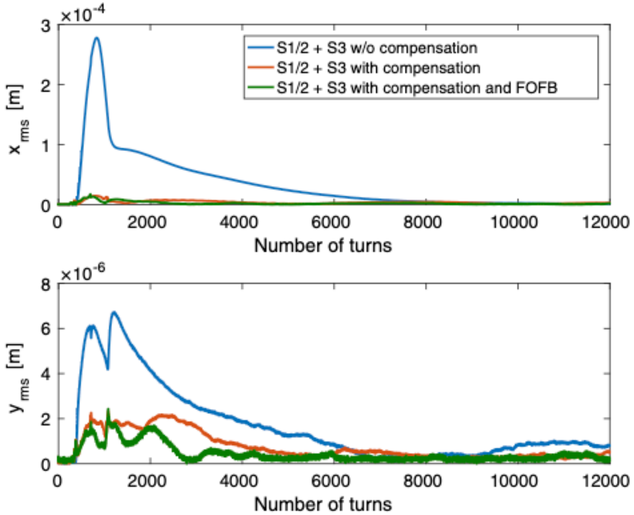




TRANSVERSE INJECTION PERTURBATIONS (B. ROCHE, S. WHITE)

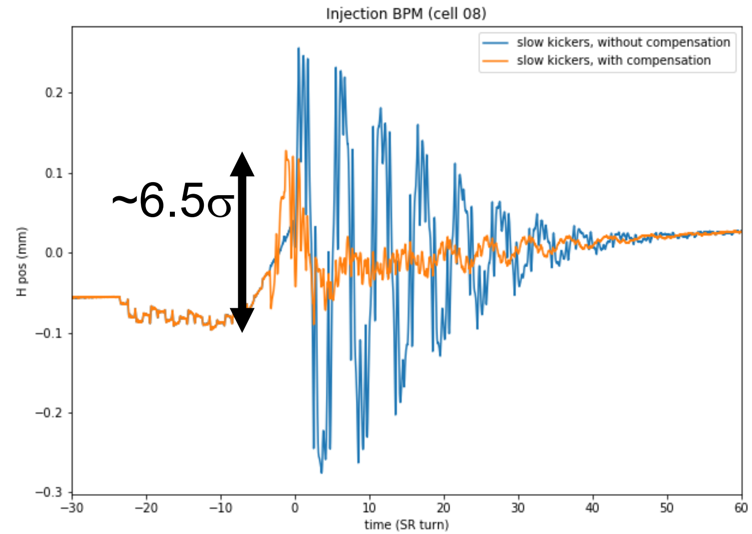
Damping of septa perturbations:

- Orbit distortion of about 200 μm, only in horizontal.
- Feedforward correction using about 10 fast correctors around injection.
- The waveform sent to the correctors lasts about 10000 turns.



Damping of kickers perturbations:

- Orbit distortion about 300 μm. It's very fast and different bunch by bunch. Mostly in horizontal, but both planes are perturbed.
- Feedforward correction using a magnetic shaker with a bandwidth of 2-3 MHz.
- The waveform sent to the shaker lasts few 10s turns.

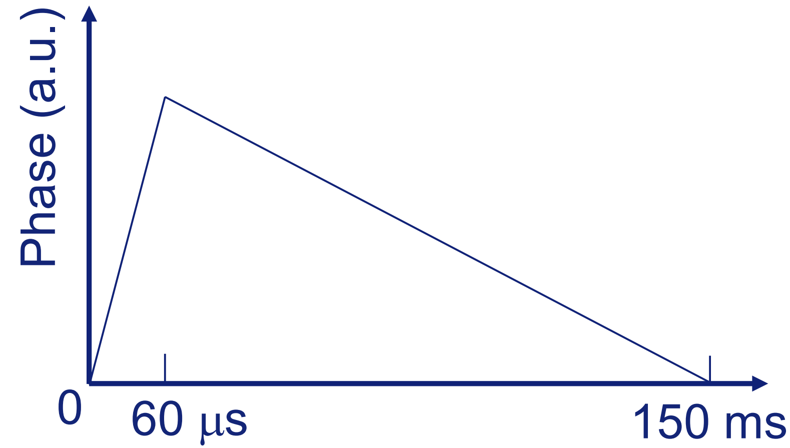


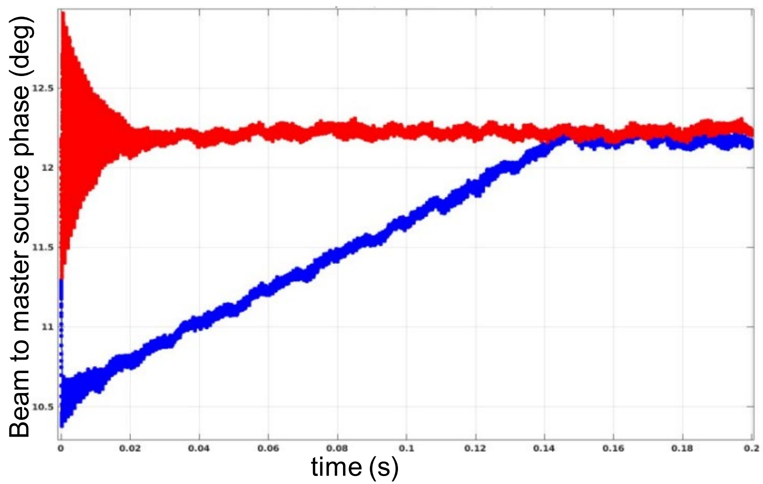
LONGITUDINAL INJECTION PERTURBATIONS (G. GAUTIER, J. JACOB, S. WHITE)

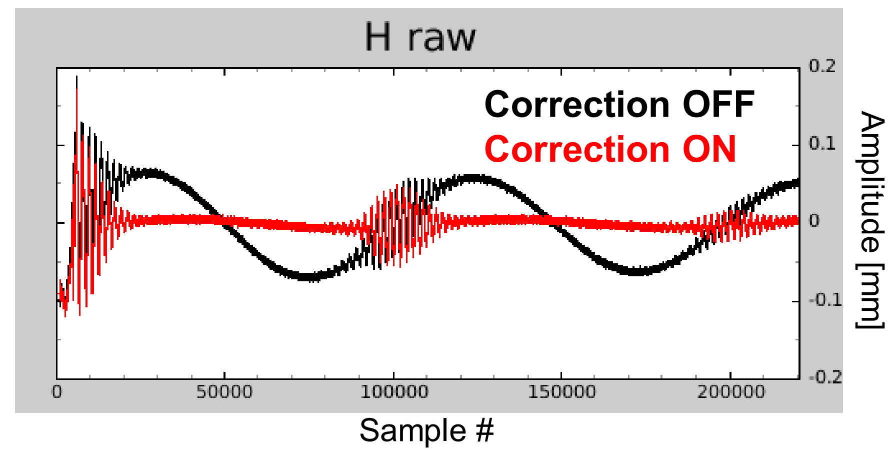
The slow kickers reduced the betatron oscillation due to imperfect closure, but introduced synchrotron oscillations due to path lengthening for about 20 turns.

Energy oscillations without compensation: $\Delta E/E \sim 0.001$

The phase of the RF cavities follows the ramp up in 60 μs and then it goes back slowly to nominal in 150 ms.







MEASUREMENT OF THE INJECTION PERTURBATIONS

	Horizontal		22/08/22
ID07	351 pm.rad	+/-	13 pm.rad
ID25	158 pm.rad	+/-	8 pm.rad

Injection perturbations are visible as emittance growth. ID07 emittance measurement is triggered right after the kicker pulse.

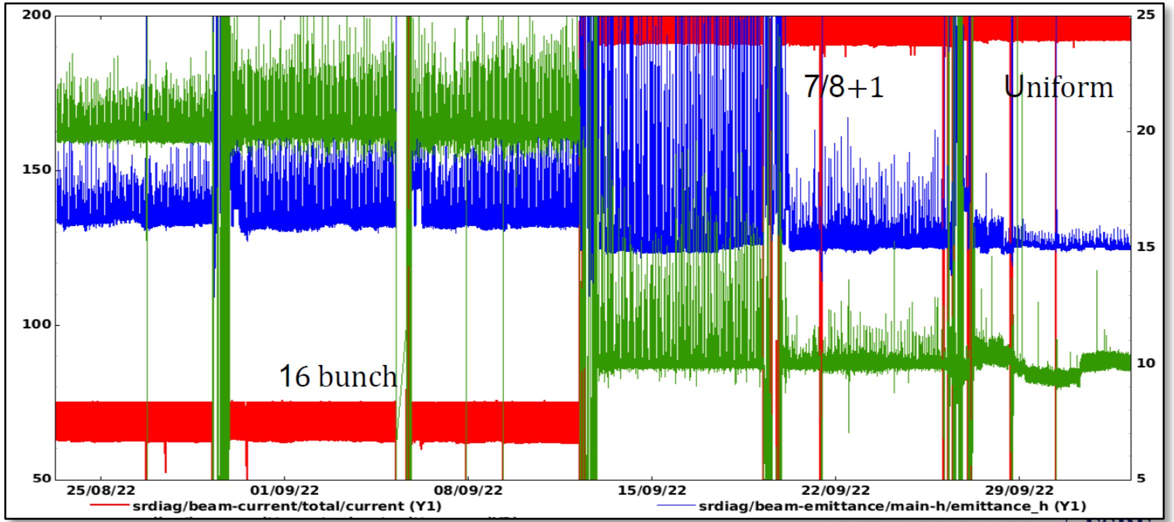
	Horizontal		26/09/22
ID07	277 pm.rad	+/-	11 pm.rad
ID25	163 pm.rad	+/-	8 pm.rad

Improvements after tuning visible also on operation tools, 16 bunch was mistuned, 7/8+1 and uniform well tuned.

$$\sigma = \sqrt{\beta\varepsilon}$$

$$\varepsilon_p = 277\ pm.rad$$
$$\varepsilon_0 = 140\ pm.rad$$

$$\sigma_p = \sqrt{\frac{\varepsilon_p}{\varepsilon_0}}\sigma_0 = 1.4\sigma_0$$



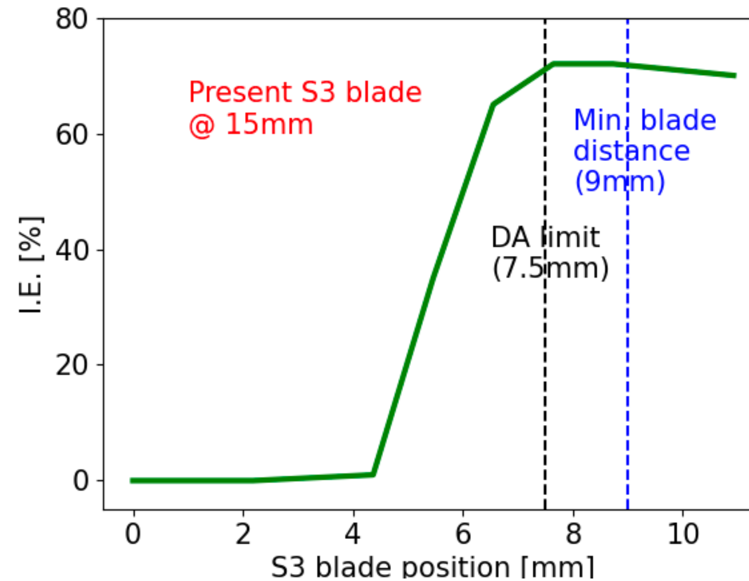
REDUCE THE INJECTION PERTURBATION BY REDUCING BUMP AMPLITUDE (S. WHITE)

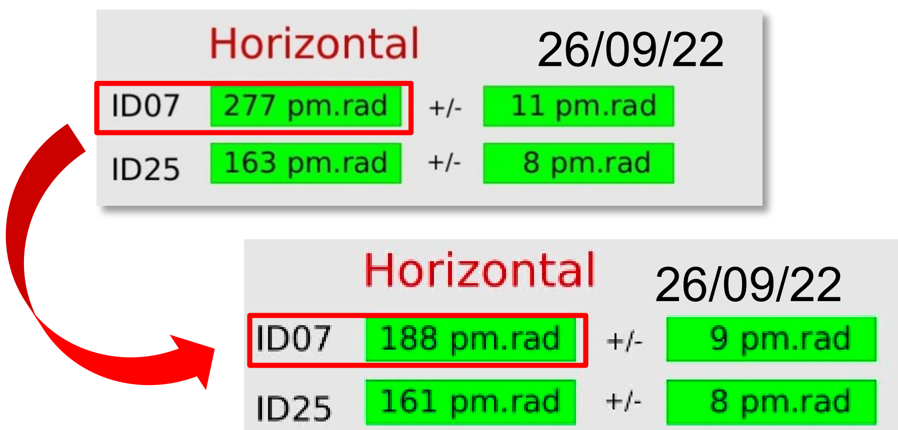
A project to reduce the perturbation is to decrease the bump amplitude by a factor 2:

- Move the S3 septum blade inwards
- Modify injection cell chambers accordingly
- **Relatively cheap solution: ~150 k€ project**

Beam experiments to verify idea:

- Move the injection cell scraper and find the limit to preserve injection efficiency
- Reduce bump amplitude **from 13mm to 8mm**: apparent emittance reduced significantly, **approaching 0.1σ**





Horizontal			26/09/22
ID07	277 pm.rad	+/-	11 pm.rad
ID25	163 pm.rad	+/-	8 pm.rad

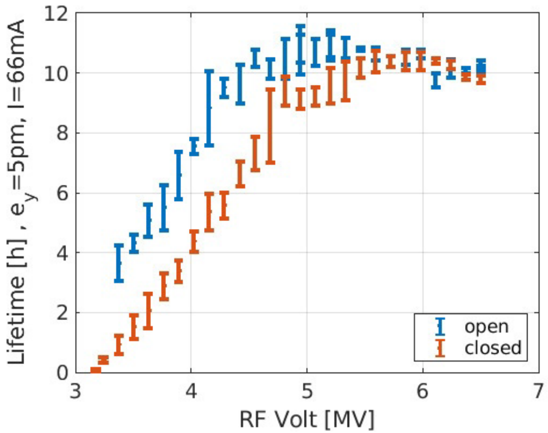
Horizontal			26/09/22
ID07	188 pm.rad	+/-	9 pm.rad
ID25	161 pm.rad	+/-	8 pm.rad

$$\varepsilon_p = 188\ pm.rad$$
$$\varepsilon_0 = 140\ pm.rad$$
$$\sigma_p = 1.15\sigma_0$$

RF ECONOMY MODE (J. JACOB)

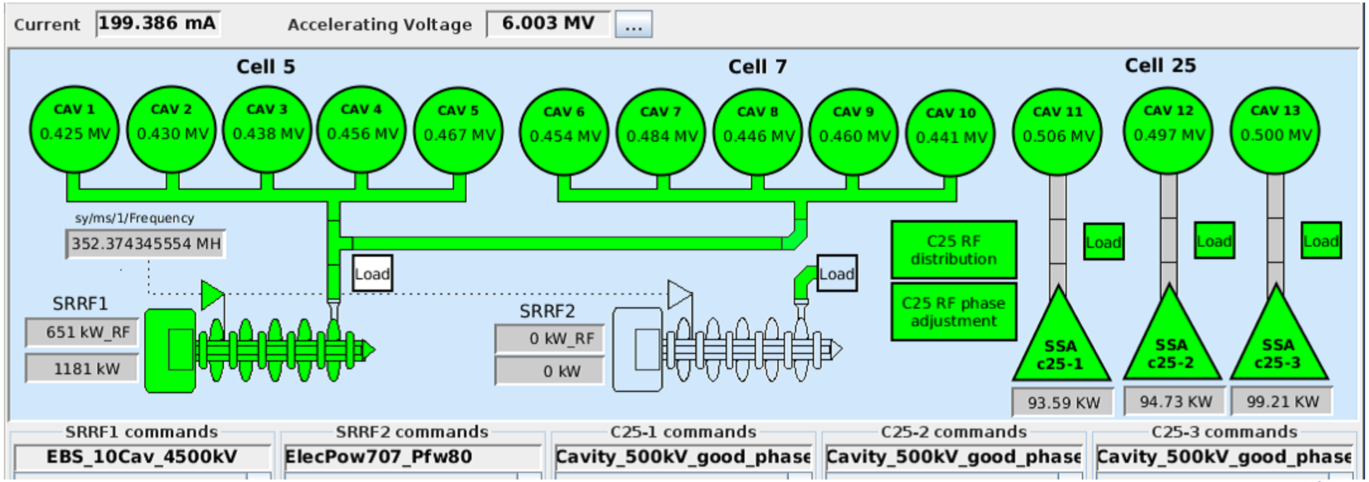
Optimum voltage for lifetime depends on the gaps setting, but it is lower than 6 MV with fully closed gaps.

Reducing the total voltage would be good to save some electricity, because the cost is very high now!



Nominal mode:

10 cavities powered with a klystron and providing 4.5 MV and 3 cavities powered by 3 SSA and providing 1.5 MV.

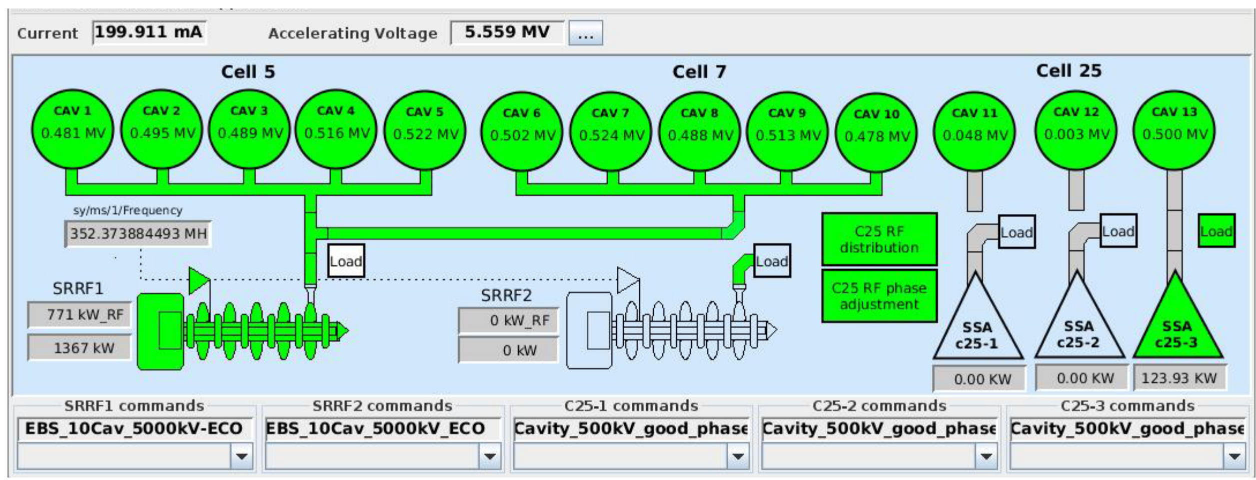


RF ECONOMY MODE (J. JACOB)

- Reduction of total V_{acc} from **6.0 MV** to **5.5 MV**
- Increase AC to RF conversion efficiency:
  - The old 150 kW SSA in cell 25 are operated below nominal power (90 …100 kW), with a low efficiency.
  - Increase the share of Klystron power by increasing Cav 1 to 10 voltage from 4.5 to 5.0 MV
  - Operate with only 1 SSA, Cav 13, at 0.5 MV

Economy mode:

10 cavities powered with a klystron and providing 5 MV and 1 cavity powered by 1 SSA and providing 0.5 MV.

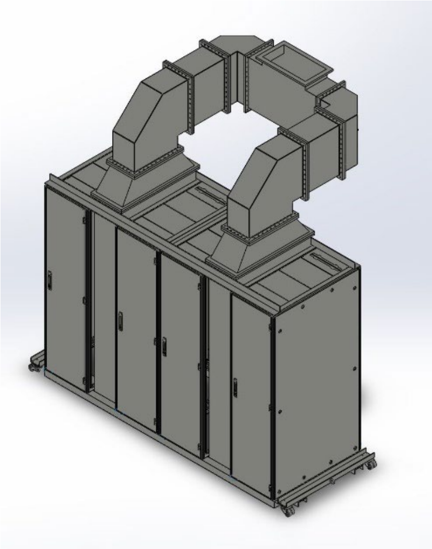


Power saved at 200 mA: ~ 200 kW

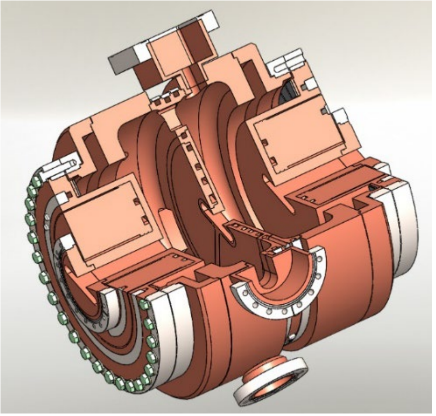
Energy saved in 1 year: ~ 1.1 GWh

TWO RF PROJECTS FOR THE NEXT YEARS (J. JACOB)

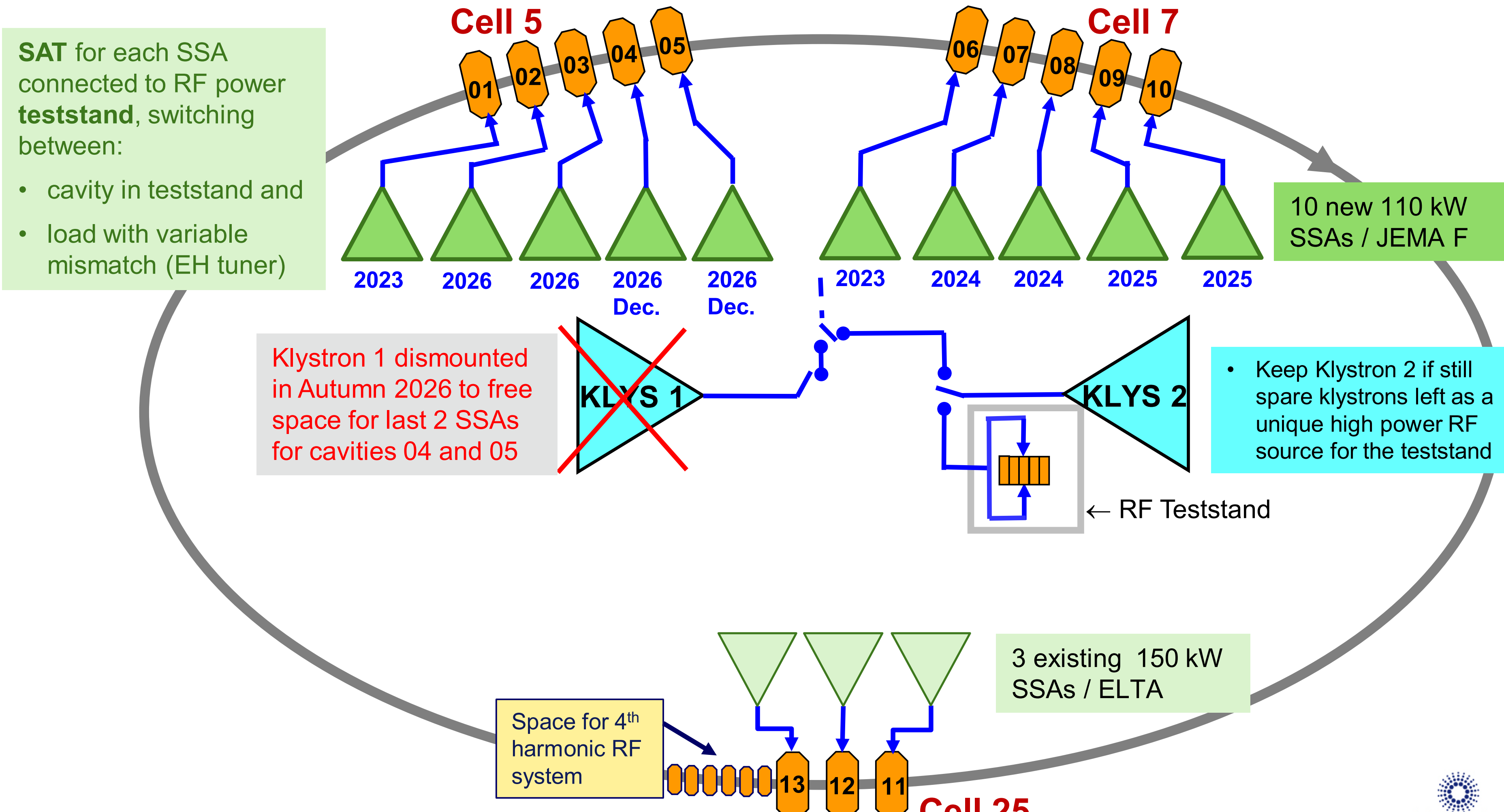
10 new 352 MHz 110 kW Solid State Amplifiers in replacement of 1.1 MW klystrons



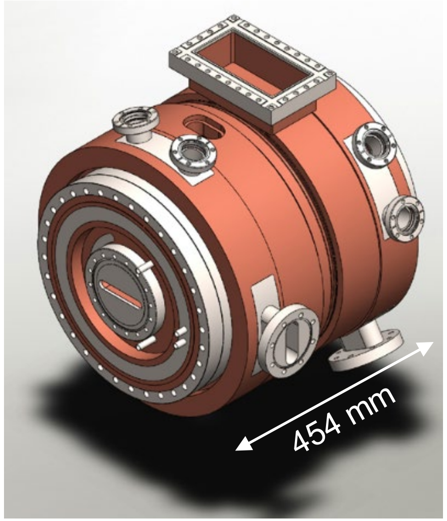
4^{th} harmonic normal conducting active cavities at 1.409 GHz

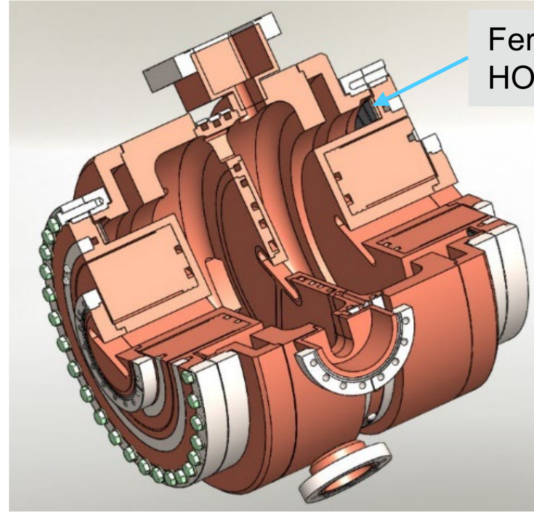


GRADUAL IMPLEMENTATION OF 10 x 110 kW SSA (P. BOROWIEC, J. JACOB)

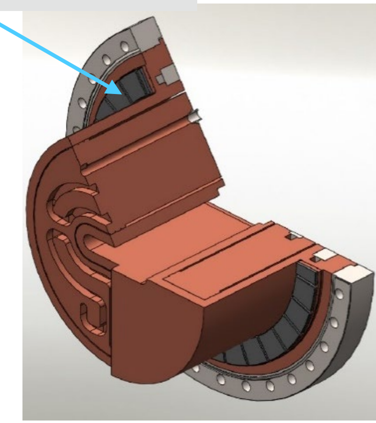


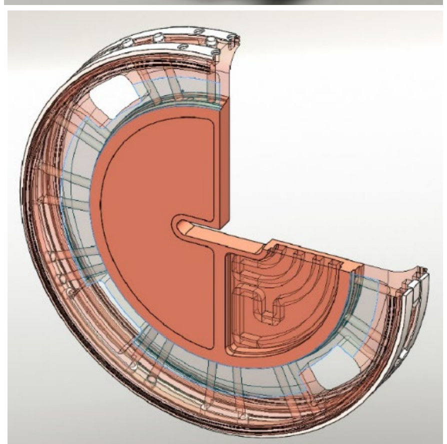
4TH HARMONIC 2-CELL E020 MODE CAVITY – IN HOUSE DEVELOPMENT (A. D'ELIA, V. SERRIÈRE, J. JACOB)





Ferrite LOM (E010 mode) & HOM absorber

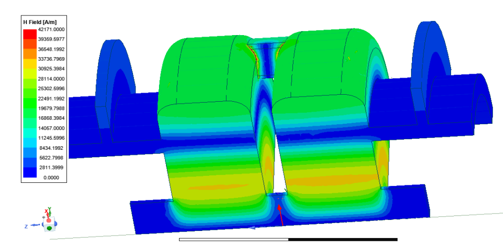




Active NC cavity design well advanced:

- ✓ 2 coupled and 2 uncoupled cells considered
- ✓ Freq = 1.409 GHz
- ✓ R/Q = 44.5 ohm/cell
- ✓ Q0 = 30500
- ✓ Smart HOM & LOM dampers almost not affecting Q0 of E020 mode
- ✓ Elaborate water cooling
- ✓ Aperture coupler: coupling β = 1
- ✓ Vacuum ports on HOM dampers also preserving Q0

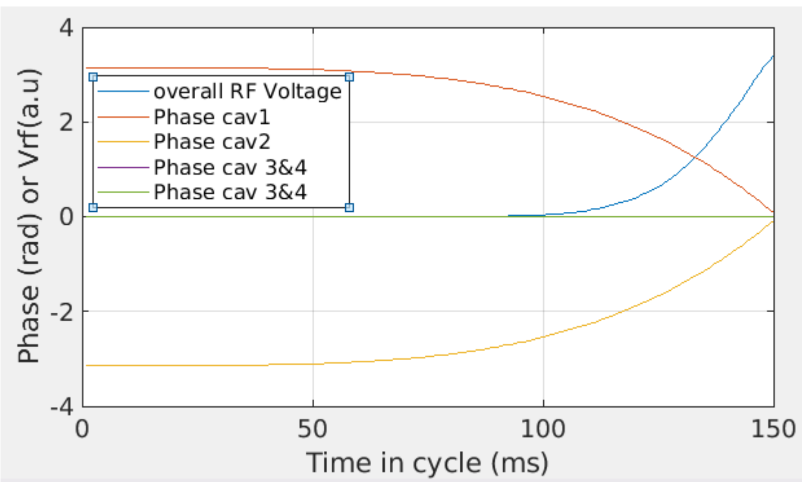
H-Field

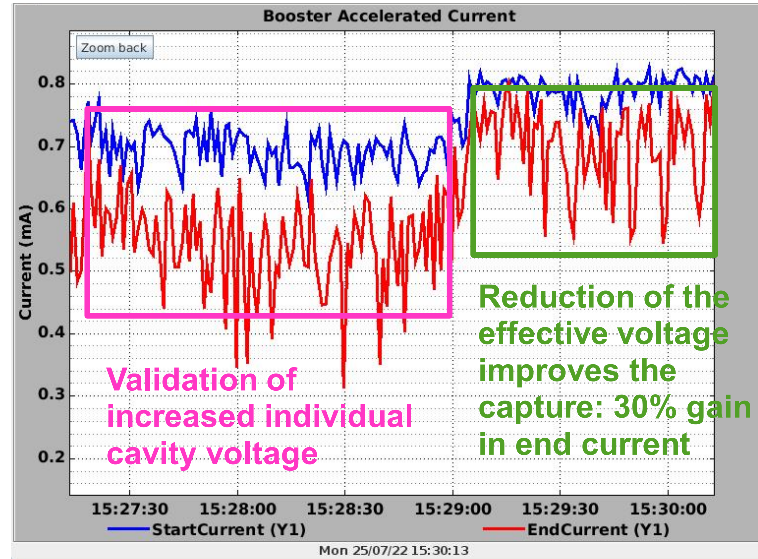


Lowering the RF voltage at injection would improve the capture efficiency and eventually the booster current

Issue: at injection when V_{rf} is low the capture is inefficient due to degraded phase regulation loops and beam loading

Proposal: set two of the four cavities in opposition of phase at injection to allow for increased voltage in individual cavities but low overall RF voltage





Phase ramped back to their optimal value during the cycle to reach high-voltage at extraction

Phase ramping of each individual cavity has been implemented and tested

CONCLUSION

- Statistics of 2022 are at the levels of the old ESRF storage ring.
- With higher coating of kicker chambers, the maximum current in timing modes are close to the design values.
- Injection perturbations are reduced thanks to slow kickers power supplies, septa compensation, kicker compensation, RF phase compensation.
- With RF economy mode we reduce the energy consumption by about 1.1 GWh per year.
- Future plans:
  - Reduce bump amplitude by a factor 2 for smaller perturbations
  - Exchange klystrons with SSAs
  - 4^{th} harmonic cavity for bunch lengthening
- Phase ramp of booster cavities allows to increase capture from the linac.

MANY THANKS FOR YOUR ATTENTION